

Feasibility Study on Solar Process Heat in Lebanon: The FreeGreenius Software

German Aerospace Center (DLR)

Institute of Solar Research

Dirk Krüger



Knowledge for Tomorrow



Overview

Software for calculation of solar energy supply and economics

Case study Lebanon



Why calculation software?

Calculate thermal power output of a solar installation during a day and the year for a given solar field and demand structure

Calculate economical data like pay back times

Optimise layout of a solar installation

Compare technologies

Homepage of **greenius**

<http://freegreenius.dlr.de/>

Greenius manual

http://freegreenius.dlr.de/images/greeniusdata/Greenius-Manual_4_1.pdf



Description of FreeGreenius

FreeGreenius is the freely available version of the software greenius which has been developed at the Institute of Solar Research of the German Aerospace Center (DLR) since several years.

- ⇒ Fast and simple performance calculations of Concentrating Solar Power (CSP) and other renewable energy systems based on hourly plant performance simulations.
- ⇒ Greenius is continuously extended e.g. to simulate also solar towers, solar process heat generation and solar cooling.
- ⇒ It offers a combination of fast technical performance calculations, economical calculations and user interfaces for parameter manipulation and analysis of the results.
- ⇒ Third party meteorological data and performance maps generated with other software tools may be integrated easily.



Description of greenius

Selected inputs for project site, technology, economics:

Position (to calculate sun position in regard to collector surface)

Local weather data file in hourly resolution

Demand profile, temperatures

Solar field size

Temperature range

Storage size

Investment costs

Costs for heat and electricity

Selected outputs:

Solar thermal power

Auxiliary power

Cash flow

Summarised results

All data available in excel

in hourly resolution

The screenshot shows the 'Collector Field' window with two tabs: 'Field Data' and 'Field Operation'. The 'Field Data' tab is active, displaying various input parameters and a table of fluid properties.

Temperatures:

- Nom. field outlet temp.: 393 °C
- Nom. mean field temp.: 342.5 °C
- Nom. field inlet temp.: 292 °C

Parasitic Modifiers:

- Constant need: 1.000 W/m² SF
- Power of field Pump: 8.300 W/m² SF

Miscellaneous:

- Mean mirror cleanliness: 97.0 %
- Shut down wind speed: 12.0 m/s
- Field availability: 99.0 %
- Degradation: 0.00 %** (highlighted with a red box)

Pipes:

- Piping loss coefficient ^{2,3}: 0.0615 W/(m² K)
- Expansion vessel losses ³: 0.0050 W/(m² K)

² headers and pipes in loops
³ referred to field size

Heat Transfer Fluid:

- type: VP 1
- Automatic calculation of fluidmass: ☒
- Maximal fluid temp.: 400 °C
- Minimal fluid temp.: 15 °C
- Total mass: 1098.87 t

density	heat cap.	temp.
kg/m³	Wh/(kgK)	°C
999	0.4928	100
866	0.6078	250
689	0.7189	400

Mass flow:

- Nom. fluid mass flowrate: 1110.088 kg/s
- Max. fluid mass flowrate: 120 %
- Min. fluid mass flowrate: 20 %
- Nominal field outlet pressure: 15 bar
- Nominal field pressure drop: 3.0 bar

Buttons at the bottom: OK, Apply, Cancel.

Example page greenius

Description of greenius

Example inputs collector field

Troughfield_Bayrouth

File Edit Costs Help

Collector Field

Field Data Field Operation

Temperatures

Nom. field outlet temp. °C

Nom. mean field temp. °C

Nom. field inlet temp. °C

Consumer start temp. °C

Parasitic Modifiers

Constant need W/m² SF

Power of field Pump W/m² SF

Miscellaneous

Mean mirror cleanliness %

Shut down wind speed m/s

Field availability % ▶

Degradation %

Pipes

Piping loss coefficient ² W/(m² K)

Expansion vessel losses ³ W/(m² K)

² headers and pipes in loops
³ referred to field size

Heat Transfer Fluid

type

Maximal fluid temp. °C

Minimal fluid temp. °C

Total mass t

Freeze prot. temp. °C

☐ Use storage cont. for freeze protection

☒ Automatic calculation of fluidmass

density	heat cap.	temp.
kg/m ³	Wh/(kgK)	°C
1008	1,145	20
818	1,297	250
612	2,095	350

OK Apply Cancel

Description of greenius

Example cash flow

Cash Flow

File Edit Help

Cash Flow

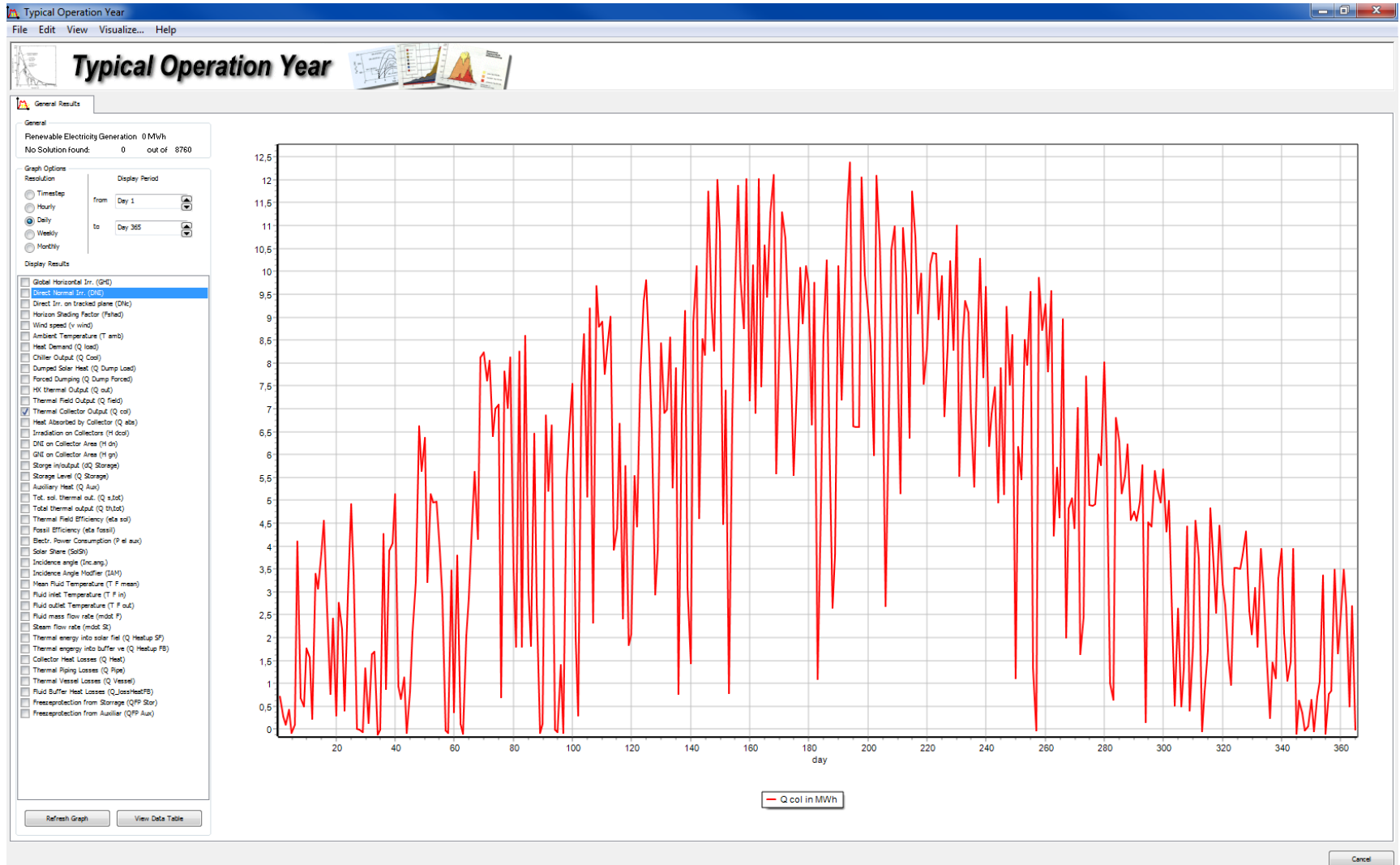
Summary Operation Construction Debt Service Depreciation and Taxes

	unit	2016	2017	2018	2019	2020	2021
Total Revenues	€	0	75.050	75.050	75.050	75.050	75.050
Total Running Costs	€	0	14.906	14.906	14.906	14.906	14.906
Net Operating CF	€	0	60.144	60.144	60.144	60.144	60.144
Investment Costs	€	975.540	0	0	0	0	0
Pre-Finance CF	€	-975.540	60.144	60.144	60.144	60.144	60.144
Grant Funding	€	0	0	0	0	0	0
Equity Funding	€	292.662	0	0	0	0	0
Debt Drawing	€	682.878	0	0	0	0	0
Debt Service	€	0	-100.838	-97.308	-93.779	-90.250	-86.721
Post Finance CF	€	0	-40.693	-37.164	-33.635	-30.105	-26.576
Tax Liability (Saving)	€	0	9.885	8.826	7.768	6.709	5.650
Post Tax CF	€	0	-30.808	-28.338	-25.867	-23.397	-20.926
Dividends Paid	€	0	-30.808	-28.338	-25.867	-23.397	-20.926
Discounted CF	€	0	-29.064	-25.220	-21.719	-18.532	-15.345
Disc. Equity Inj.	€	292.662	0	0	0	0	0
Net Present Value	€	-202.967					
Equity/Dividends	€	-292.662	-30.808	-28.338	-25.867	-23.397	-20.926

Cancel

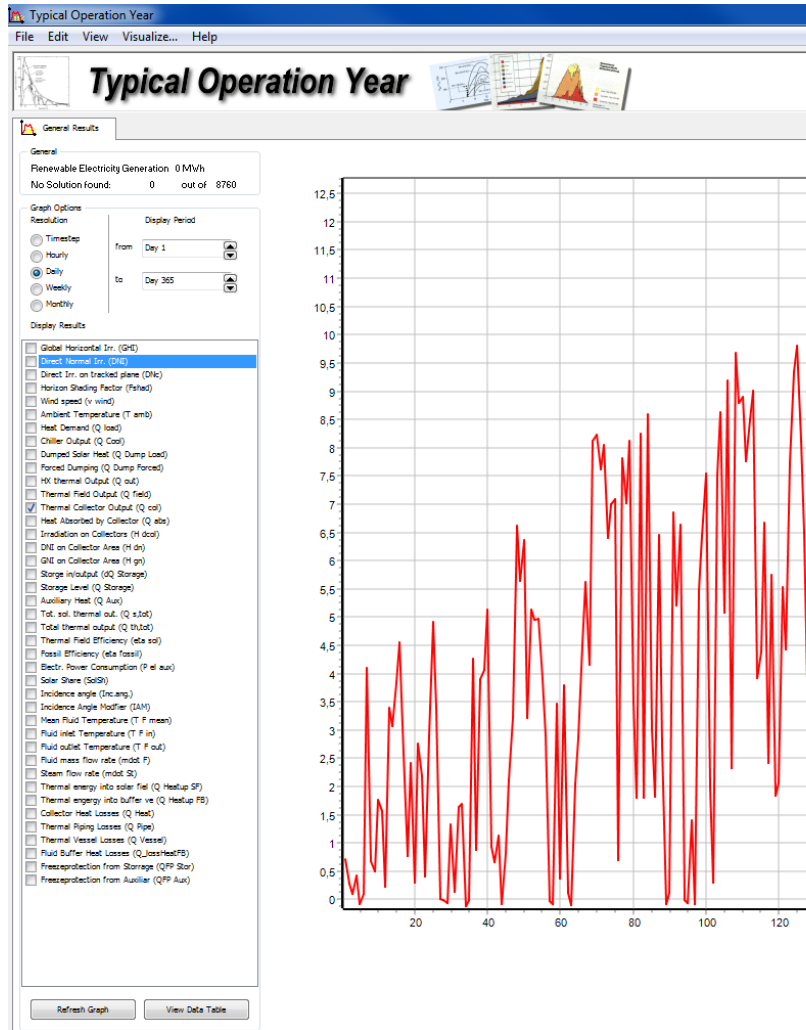
Description of greenius

Example profiles



Description of greenius

Example profiles



Graph Options

Resolution

- ☐ Timestep
☐ Hourly
☒ Daily
☐ Weekly
☐ Monthly

Display Period

from Day 1

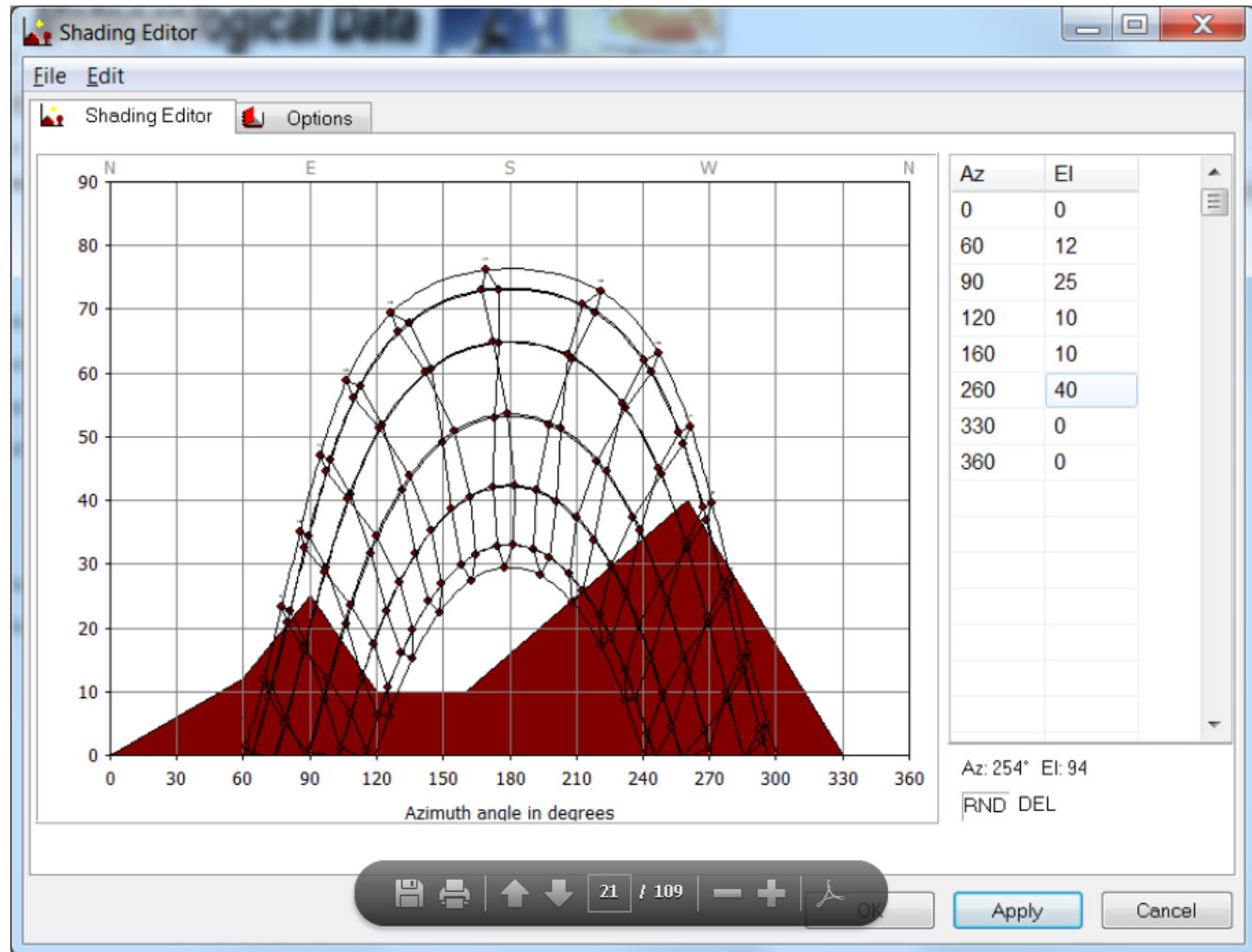
to Day 365

Display Results

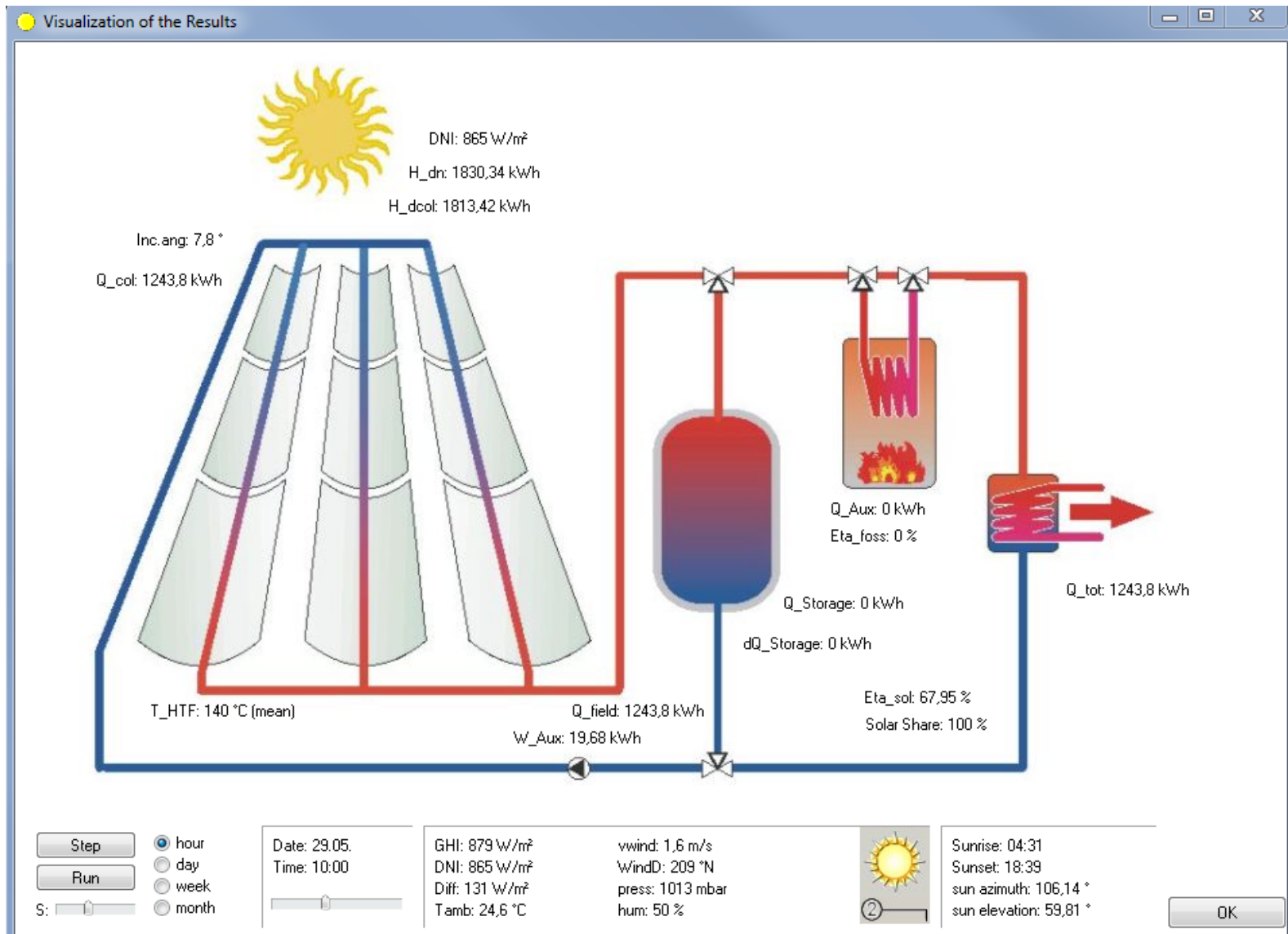
- ☐ Global Horizontal Irr. (GHI)
- ☒ Direct Normal Irr. (DNI)
- ☐ Direct Irr. on tracked plane (DNIc)
- ☐ Horizon Shading Factor (Fshad)
- ☐ Wind speed (v wind)
- ☐ Ambient Temperature (T amb)
- ☐ Heat Demand (Q load)
- ☐ Chiller Output (Q Cool)
- ☐ Dumped Solar Heat (Q Dump Load)
- ☐ Forced Dumping (Q Dump Forced)
- ☐ HX thermal Output (Q out)
- ☐ Thermal Field Output (Q field)
- ☒ Thermal Collector Output (Q col)
- ☐ Heat Absorbed by Collector (Q abs)

Description of greenius

Shading editor



Description of greenius



Lebanon example calculation

Lebanon-Bayrouth

File Edit Tools Help

Location

Geographical Location

Name: Lebanon-Bayrouth

Latitude: 33,82 °N Altitude: 18 m

Longitude: 35,48 °E

Timezone: +2 (East European Time)

Solar Angles for this Location

Date: 26.07.2016 Day Length: 13:54 h

Sunrise at 04:47:12 (Azimuth 66,07°)

Sunset at 18:41:37 (Azimuth 293,76°)

Solar noon at 11:43:25 (Elevation 75,47°)

Properties of Ground

Ground structure: Sand


Roughness length: 0,03 m
flat country, pasture

Albedo factor: 0,2
unspecified

Average slope: 3 °

specific Land costs: 1 €/m²

Image of Location



OK Apply Cancel

Lebanon example calculation

Collector technology: Parabolic Trough (alternativ Fresnel)

Collector field size: 2116 m²

Assumption all solar energy consumed

Temperature from solar field: 200°C

Maintenance 1 €/(m²*a)

Replacement costs 0.2%/a

Insurance costs 0.8%/a

Assumed costs per m² of collector surface: 300 €/m² installed plus land costs, civil works, foundations, fence and freight, project development, supervision (*Specific costs lower with greater size!*)

Estimated total investment costs 975,540 €

Financial Input Parameters:

Heat Tariff	0,0400	€/kWh_th
Grant Proportion (Renewable)	0,00	%
Debt-Equity-Ratio	70,00	%
Average Interest Rate	5,64	%

High uncertainty about conditions in Lebanon



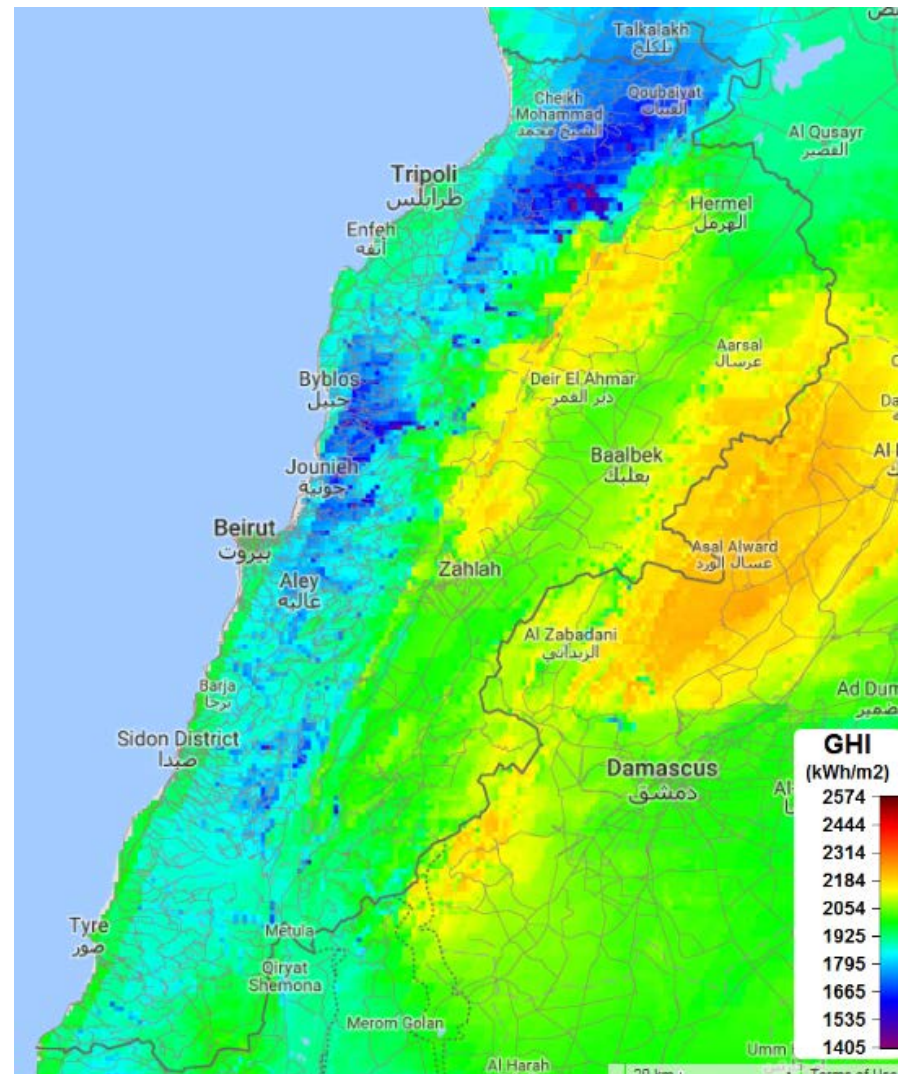
Weather data Beirut used for calculation

Data from MeteoNorm in hourly resolution:

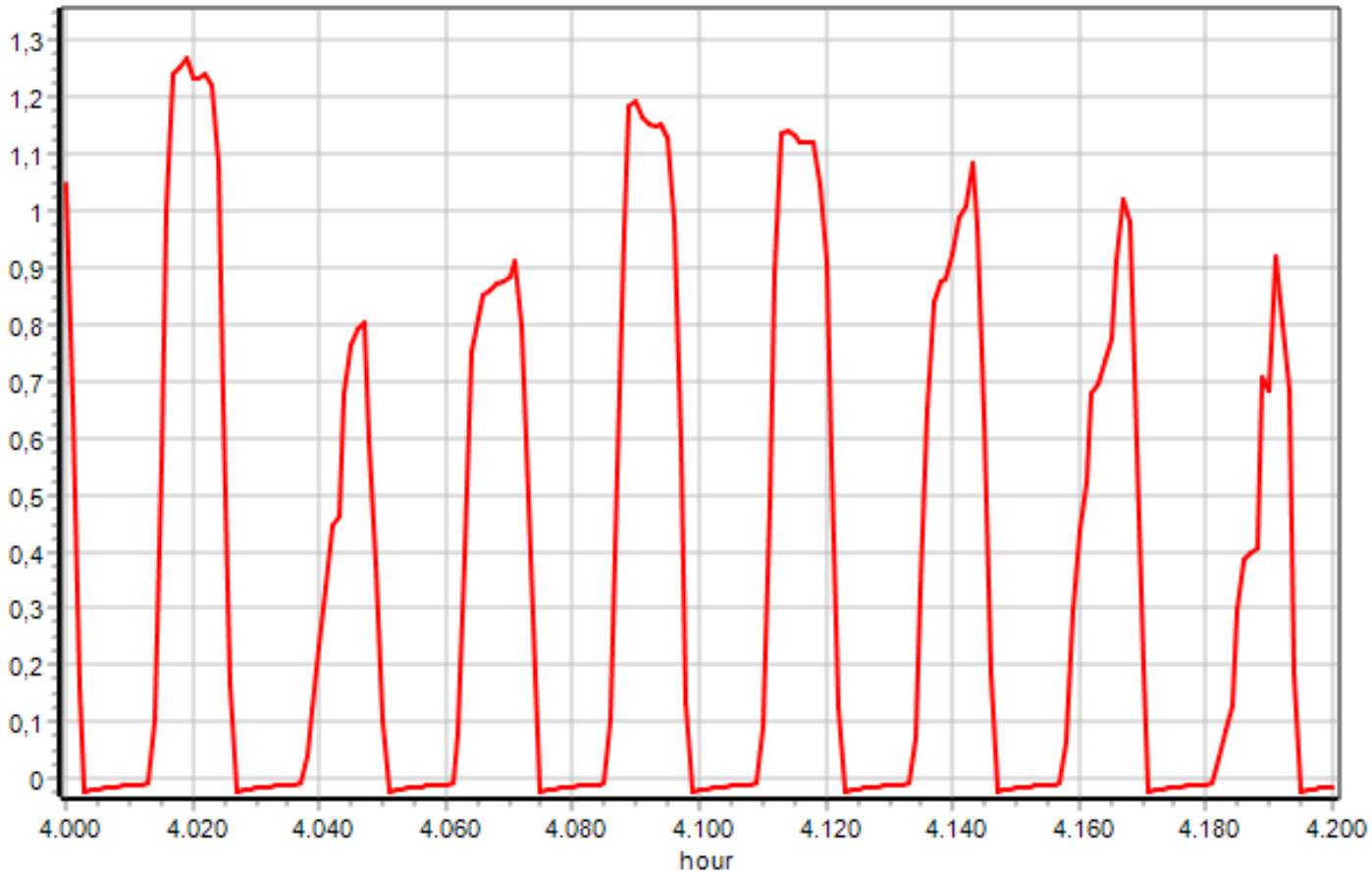
DNI (Direct Normal Radiation)

Ambient temperature

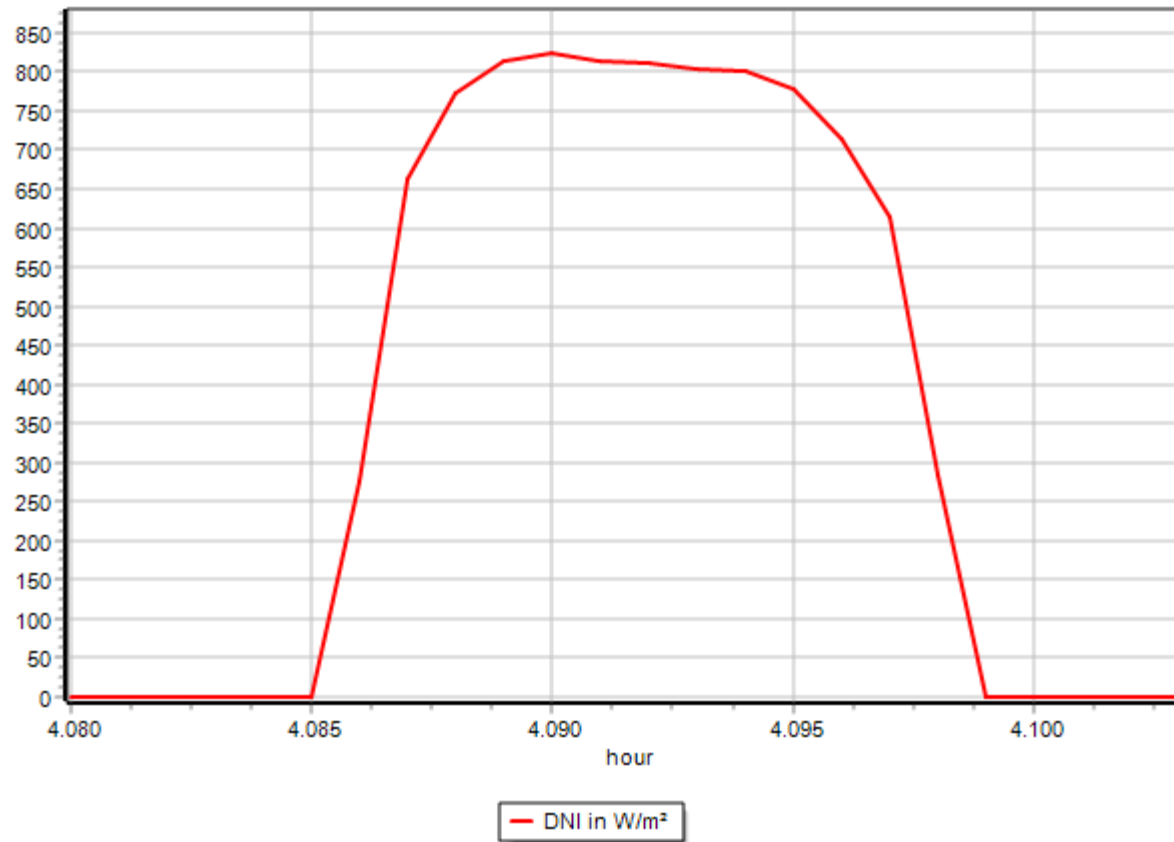
(Annual DNI in Beirut: 1864 kWh/m²)



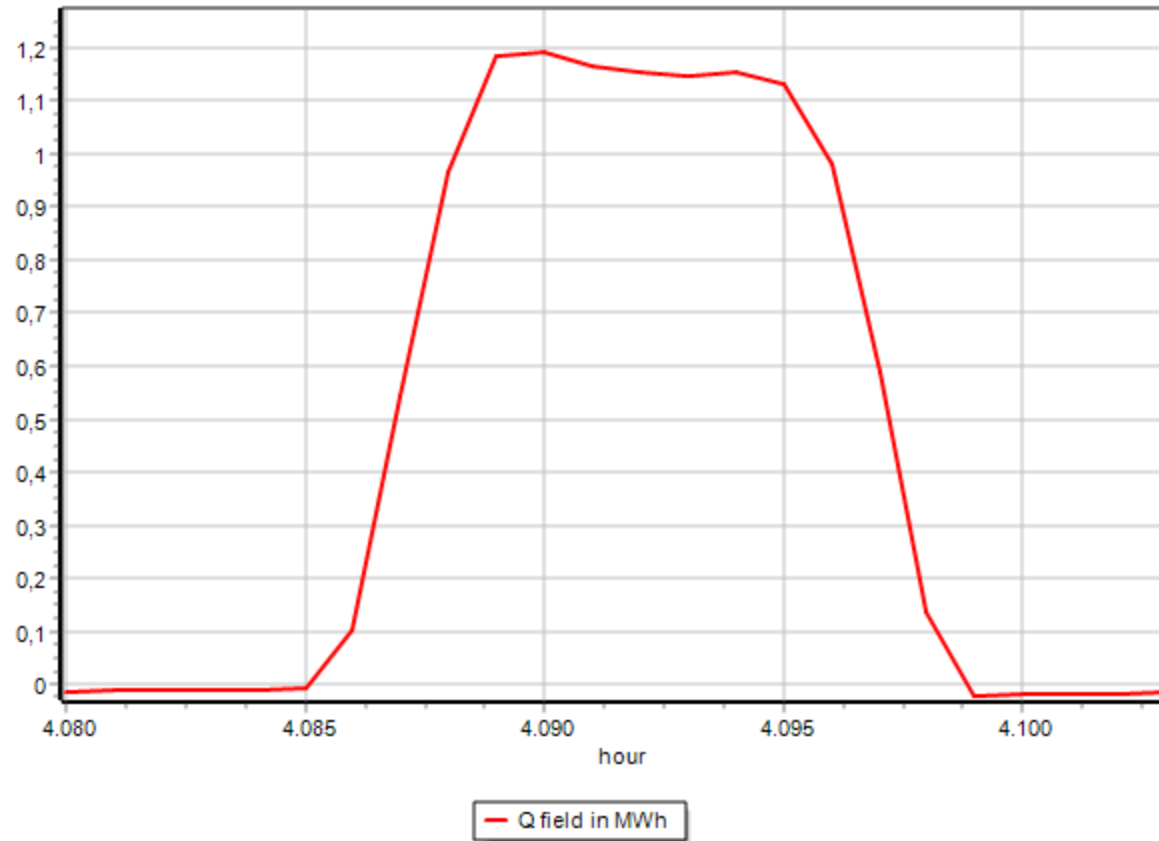
Solar field thermal production during several days in June



Solar field thermal production one day in June



Solar field thermal production during several days in June



Technical Key Results

Direct normal irradiance (DNI)	1864	kWh/(m ² ·a)
Annual solar heat generation	1,876	MWh _{th}
Specific thermal field output	886,69	kWh _{th} /m ²
Mean annual field efficiency	47.57	%
Solar share	100.00	%
Annual electricity consumption	29	MWh _{el}



Economical Key Results

Simulation Results:

Internal Rate of Return (IRR) on Equity	1,96	%
Net Present Value	-202.967	€
Payback Period	21	yrs.
Levelized Heat Costs (LHC)	0,0463	€/kWh_th
Annuity of Investment Costs	0,08	
NPV of Running Costs (OC)	135.248	€

Environmental Aspects:

Annual CO2 Reduction 562,88 t CO2

Other data given as annual values e.g. revenues, debt service etc.

The required heat price is 0.079 €/kWh to match the minimum required IRR of 12%

Check financial parameters – no inflation included



Improving chances for solar process heat projects

Cost reduction via local production

Create awareness and know-how about the technology

Create motivation in industry through local production

Funding through e.g. EU projects

Creating awareness that solar energy provides price stability

National programme including subsidies

Drive costs down by experiences from installations



Summary

No examples for such installations in Lebanon - so still high uncertainty

National heat demand structure investigated?

Local share unknown – who can assist in building and maintenance of installations?

Good radiation potential in Lebanon

Demonstration projects necessary to gain experiences

